2015-05-31

CAD Interoperability for Navy Reuse in 3D Printing, Maintenance and Training

Sadagic, Amela; Brutzman, Don

Monterey, California. Naval Postgraduate School

Field Trip Report

Authors: Dr. Amela Sadagic and Dr. Don Brutzman

Project: CAD Interoperability for Navy Reuse in 3D Printing, Maintenance and Training

Topic Sponsor: N41

POC: CAPT Frank Futcher, US Navy, OPNAV, N41

Locations visited (funded by the project):
Port Hueneme, CA
SPAWAR, San Diego, CA
USS BOXER, San Diego, CA

Events attended (not funded by the project):
Maker Faire, San Mateo, CA
VR Hackathon, San Francisco, CA

Dates of Visit & events: 11 - 13, 17 and 24 May, 2015

Date: 31 May, 2015

Contents

1 General Information

Travel and field visits to Port Hueneme, San Diego and VR Hackathon have been planned in support of major research activities on the project "CAD Interoperability for Navy Reuse in 3D Printing, Maintenance and Training." Additional insights related to technology field were derived from the visit to Maker Faire and VR Hackathon (not supported by project), and were added to complement our growing knowledge about this domain.

2 Participants from NPS

- Dr. Amela Sadagic, project Principal Investigator (PI)
- Dr. Don Brutzman, project co-Principal Investigator (co-PI)

3 Visits and Events

3.1 Port Hueneme, CA

- Date: 11 May, 2015
- Objectives: Following objectives have been planned and accomplished during this field visit:
  - Being that this was the first time many people in the group met, the main goal was to introduce all members and learn more about their work and expertise, as well as about the work of the institutions they are affiliated with.
  - Acquire clear understanding about each institution interest, expertise and engagement in wider domain of additive manufacturing (this includes the work with 3D models).
  - Develop concrete suggestions for future collaboration.
- POCs:
  - Kail Macias
  - Cody Reese
  - Greg Wakatsuki
  - John Kunsemiller
- Other Participants:
  - Alex Viana, PMP, Facilities Integrated Product Support, NAVFAC HQ
  - Philip Vitale, NAVFAC HQ (called in from DC)
  - Alan Jaeger, Center for Asymmetric Warfare, NPS
- Discussions:
  - Mission and domain of NAVFAC activities was reviewed for the benefit of the guests from NPS.
  - Cody Reese introduced elements of NAVFAC activity in additive manufacturing domain, and presented parts they printed using their 3D printer STRATUS 1120 (photos enclosed in Section 4 of this document).

- A widespread use of 3D in all domains supported by NAVFAC (Illustration on Figure 1 - almost all pamphlets that presented different elements of NAVFAC mission presented 3D models.
- **2D blueprints**: Errors in 2D blueprints are common and detrimental to the business. An example of the company that specializes in detecting and correcting errors in 2D blueprints, was mentioned. While 3D models have their own issues, the correctness of their geometry is easier to inspect in both 3D viewer and automated algorithms, and as a result the number of errors is greatly reduced.
- **Last tactical mile**: Significance of the last tactical mile from the maker to the ship.
- **Categories of situations** supported by 3D printing: 3D printing used for two general categories/situations: (1) printing of the final part that gets installed, (2) printing of physical object that serves as prototypes. (Note: We will use this categorization in our future work and documents). Example of 3D printed parts being used as mockup/prototype models: to conduct rehearsal before actual maintenance operation.
- **3D models owned by NAVFAC**: NAVFAC in DC: Owns models of ports and waterfronts - over 100 installations (some have 3D models some do not); collectively they represent shore facilities.
- **3D models and model interchange**: 3D models and model interchange is deeply connected to additive manufacturing, and advances in that field will directly benefit a domain of additive manufacturing.
- **Management of 3D models** (storage, transformations, updates) needs a comprehensive solution.
- **Issue to consider**: quality control of printed parts
- **To be determined**: What parts would need to be built from scratch and what parts are good candidates to scan with 3D scanner (note: this is the issue that NPS team plans to pursue in our project). This effort should provide a general guidance and metrics.
- **Example**: NAVAIR found that in one program 96% of 2D drawings/ blueprints were wrong and only 4% were correct. Issue: Ambiguity and ease of making a mistake in 2D blueprints; 3D visualization vs 2D diagrams
- **Example**: Water purification system in Guantanamo Bay. Without part that got broken it had 1/2 capability for water supply. Being that the part was no longer in production and the fact that this facility was remote, the cost to manufacture and deliver 2 parts for the pump was $392K.
- **Example**: Some parts get purchased in advance and stored in large warehouses because of the fear the companies that used to make them will either stop doing that or they will go out of business altogether. Total cost: cost of parts that were purchased 'in advance' and cost of those storage facilities.
- Another group that we should connect to: NAVSEA and their Working Group for 3D Printing.

- <u>Action Items</u>:
  - Expand collaboration and initiate future joint efforts. Include the use of NAVFAC 3D models.

- Establish shared information resource and discussion forum (NPS lead).
- Make connections with colleagues from NAVSEA.

3.2 SPAWAR, San Diego, CA

- Date: 12-13 May, 2015
- Objectives: Following objectives have been planned and accomplished during this field visit:
  - Acquire clear understanding about each institution interest, expertise and engagement in wider domain of additive manufacturing (this includes the work with 3D models).
  - Exchange understandings, concerns, issues and opportunities so far identified in domain of additive manufacturing.
  - Develop concrete suggestions for future collaboration
- POCs:
  - Dan Green, SPAWAR Taskforce Innovation
  - Scot Miller, NPS, SPAWAR
- Other Participants:
  - Alex Viana, PMP, Facilities Integrated Product Support, NAVFAC HQ
  - Philip Vitale, NAVFAC HQ (called in from DC)
  - Chris Buthe, Supply Chain Specialist, CMTC
- Discussion:
  - Chris Buthe: He introduced the work done by CMTC and his collaboration with NIST (slide set shared during the meeting).
  - **Large concepts** (need to adopt shared definitions): (1) Manufacturing operations across Navy enterprise, (2) Digital asset management, (3) Expeditionary 3D printing.
  - **3D printing vs commoditization**: Commoditizing design and manufacturing, Mass-customization (opposite from commoditization). Additive manufacturing could be seen as turning the supply chain inside out.
  - **3D Model Based Ecosystem**: Need to define the elements of this environment.
  - 80% of the workflow is digital.
  - **Unintended errors in 3D models**: 3D models could change due to the (a) presence of dirt (when physical artifact is scanned), (b) data corruption (intentional by 3rd parties) or (c) translation distortion.
  - Other members of consortium: NAVSEA, NAVAIR
  - **Define demonstrations and experiments**: Testing baseline capabilities (Note: NPS project incorporates selected set of tests and demonstrations).
  - NAVFAC role in additive manufacturing initiative needs to be clearly defined.
  - **Metadata**: Importance of this information being part of 3D model. Cross-connectivity of 3D models in different domains.
  - **Issues to consider** relevant to additive manufacturing: QA/QC (quality assurance / quality control).
  - Manufacturing readiness in SW region as a topic of our focus and effort.

- Lifecycle Management (LM) and Automation.
- **X3D data format** as a candidate format for 3D model safekeeping and long- term archival stability.
- Need to re-use the assets that are already paid for.
- **Situation now**: Additive manufacturing looked at as an engineering challenge, still not seen as an operational challenge.
- **Project JAMR**: bigger picture is emerging.
- **Acquisition**: new model of acquisition that will incorporate additive manufacturing.
- When testing the system: effectiveness (can it do some function or not / boolean), efficiency (how well can it do that function; includes user performance), user satisfaction (learnability, ease of use).
- **Categories of installations** where additive manufacturing can be applied: (1) ships with machine shop i.e. they can machine some parts but still not all that they may need, (2) ships without machine shops but which can accommodate 3D printer/scanner; (3) shore facilities. (Note: We will use this categorization in our future work and documents).
- **Terminology**: Additive manufacturing --> Advanced Manufacturing
- **Deployment strategy**: Web
- **Issues to consider**: security, cyber, IP (intellectual property).
- Team attended training session that demonstrated capabilities of Solidworks 3D CAD software. Emphasis of the session was on data management.
- Dr. Mark Bilinsk showed SPAWAR results with using LIDAR technology to scan indoor and outdoor large scale environments; Lidar data acquired from UV that was flying over the shore installation;
- The team had phone a discussion with JD Morrison, C3F Science Advisor; Discussed IP issues, certification of plans, certification of produced parts, example: news story about counterfeit bolts that failed under load. He was receptive to possibility of proposing the work with USS ESSEX and USS BOXER.
- The team met with Mike Stewart and Kevin Walsh, and discussed DISR standards.

- Action Items:
  - **Establish a consortium of Navy institutions:** Organize periodical meetings when different topics would be discussed, and information shared. (SPAWAR/Dan Green as a lead).
  - **Design demonstrations, test and experiments** that will contribute to the growing body of knowledge in this domain. Define hypothesis and metrics.
  - **Initiate cataloging activity**: institutions and people who work is closely related to additive manufacturing; 3D printing technologies; 3D printers; systems and tools in support of additive manufacturing; research studies; web articles; examples of innovative use of additive technologies; examples of additive manufacturing being used in Navy and DoD; issues associated with domain of additive manufacturing that should be addressed (example: intellectual property, cyber security). Check what elements of this effort have been done by other partners, and avoid duplication. (NPS lead)

- Identify the elements of 3D Model Based Ecosystem.
- Establish a shared information resource and discussion forum (NPS lead).

3.3 USS BOXER, San Diego, CA

- Date: 13 May, 2015
- Objectives: Learn about ship practices related to maintenance domain, including the work of their machine room and management of spare parts.
- POCs:
  - LCDR Kenneth Maroon
- Other Participants:
  - Alex Viana, PMP, Facilities Integrated Product Support, NAVFAC HQ
- Discussions:
  - **Discussion with a machine room crew** generated extremely useful insights in terms of their readiness to add 3D printing to their mission. We met 5 members of their crew and all of them were cognizant about 3D printing; each member also owned game console and smart phone; they could be ideal first adopters (note: endorsement still needs to come from the leadership). They also mentioned use of 3D printing as a way to save time to manufacture parts; this would be especially the case when the number of jobs they need to do is large and therefore some level of automation would be helpful (possible better/more effective use of manpower). 3D printing would also represent a better use of material as only necessary quantity gets used. Currently both the stock metal supply room and the amount of scrap material that gets discarded, are fairly voluminous (members of the crew do try to re-use parts and pieces that were once scrapped).
  - **Significant finding** from the machine shop: we found that the workflow of the machinists was totally 'analog' and by hand, matching their "A" school training. Furthermore the workflow of damaged part diagnosis reconstruction, testing and repair, exactly echoed the digital workflow we have proposed. This bodes very well that 3D printing processes can be incorporated into the fleet procedures; clearly this approach would work for large ships, and it can likely be extended for smaller ships as well.
  - **Note related to diffusion of innovation**: Investigate and propose programs and approaches that would provide support network to innovators and first adopters in Navy (our example of young sailors in machine room).
  - Mentioned that SPAWAR team form East Coast conducted 3D large scan of the ship (we received contact information afterwards).
- Action Items:
  - Add sister ships USS BOXER and USS ESSEX to future test sites simultaneously, so that experimentation can be conducted both afloat and in port as needed. (NPS initiative, potential extension of FY16 effort)

3.4 Maker Faire, San Mateo, CA

- Date: 17 May, 2015
- Objectives: Identify trends and innovative solutions in domain of 3D printing and supporting technologies (example: 3D scanning).
- Participant:
  - Dr. Amela Sadagic
- Discussions:
  - Maker Faire is typically seen as both science and county fair, but also as an informal platform where large and small makers of novel technologies, approaches and devices bring their solutions for the first test with the audience/visitors.
  - **Trends**: A number of 3D printing systems have been brought to Maker Faire in recent years, and over the time we came to identify trends in this domain: (1) solutions are becoming far more robust and companies come to exhibit their solutions year after year; (2) users' support networks are important factor in companies' success; (3) characteristics that help printing differentiate themselves from others: a) faster printing, b) type of material used for printing (example: resistant to high temperatures), c) fidelity of printed artifacts; (4) a whole host of DIY solutions (3D printers printing the parts for new printers); (5) printers that require smaller 'housing' space and have sizable working/printing space; (6) 3D printers that serve as 3D scanner (dual use of the working space inside the printer).
  - Photos in Section 5 show examples of 3D printed parts done by company Windform SP. The photos show elements of their additive manufacturing program that uses composite polyamide based carbon filled material.
    - Windform company web site: http://www.windform.com
    - Printing paterial: http://www.windform.com/windform-sp.html
    - Spec: http://www.windform.com/PDF/SCHEDA_WF_SP_ENG.pdf
  - Artec 3D (http://www.artec3d.com) company exhibited their 3D scanning solutions - handheld devices Artec Eva and Spider. Technical specs of both devices suggest high 3D point resolution and accuracy (Artec EVA: 0.5 mm / 0.1 mm; Spider: 0.1 mm / 0.05 mm). While the price is currently prohibitive for mass deployment (Artec EVA: $19,500; Spider: $22,600), the hope is that with time and adoption of those devices, especially working in concert with 3D printing will go down.

3.5 VR Hackathon, San Francisco, CA

- Date: 24 May, 2015
- Objectives: Support Bay Area VR community, identify trends and innovative solutions in VR domain.
- Participants:
  - Dr. Don Brutzman, Dr. Amela Sadagic

- Discussions:
    - We participated as domain experts and judges. The emphasis on 3D models and technologies that support different formats was our primary interest (connection between 3D models and interchange, and additive manufacturing).
    - **Trends**: Majority of teams used VR headsets (immersive technology) in their projects - some were dedicated VR displays (example: Oculus Rift) and some used mobile devices i.e. smart phones as displays and processing units (Samsung, Google cardboard). The symptoms of cybersickness identified; some symptoms could be alleviated by using a high speed hardware that reduces latency. According to Chris Peri (Samsung), latency has been reduced but it is still off by a factor of 10 - current lag in head tracking systems is 100 ms, and his estimate is that 10 ms will be needed.

4 NPS Action Items and Ideas for Future Work

NPS will consider following action items and future work:

- Establish a shared information resource and discussion forum. This effort will be led by NPS (investigation on how to approach it have already begun).
- Add the idea of establishing collaboration with 3 test sites that would be our first adopters and testers of different elements of additive manufacturing processes, including the augmented maintenance workflow that will result from this year's project effort. Potential sites: USS BOXER, USS ESSEX, and one shore facility. It should be noted that if we get the workflow functioning properly with the crew and ships that have machine rooms, it will later be possible to adapt it to ships that do not have machine room.
- Contribute to design demonstrations, test and experiments that will add to the growing body of knowledge in this domain.
- Plan for our potential future contribution towards joint X3D Stress Test effort proposed by Dan Green (work with Alex).
- Connect with other Navy colleagues (NAVSEA and others).

5 Photo Illustrations

Figure 1: Visit to NAVFAC, Port Hueneme, CA (11 May, 2015)

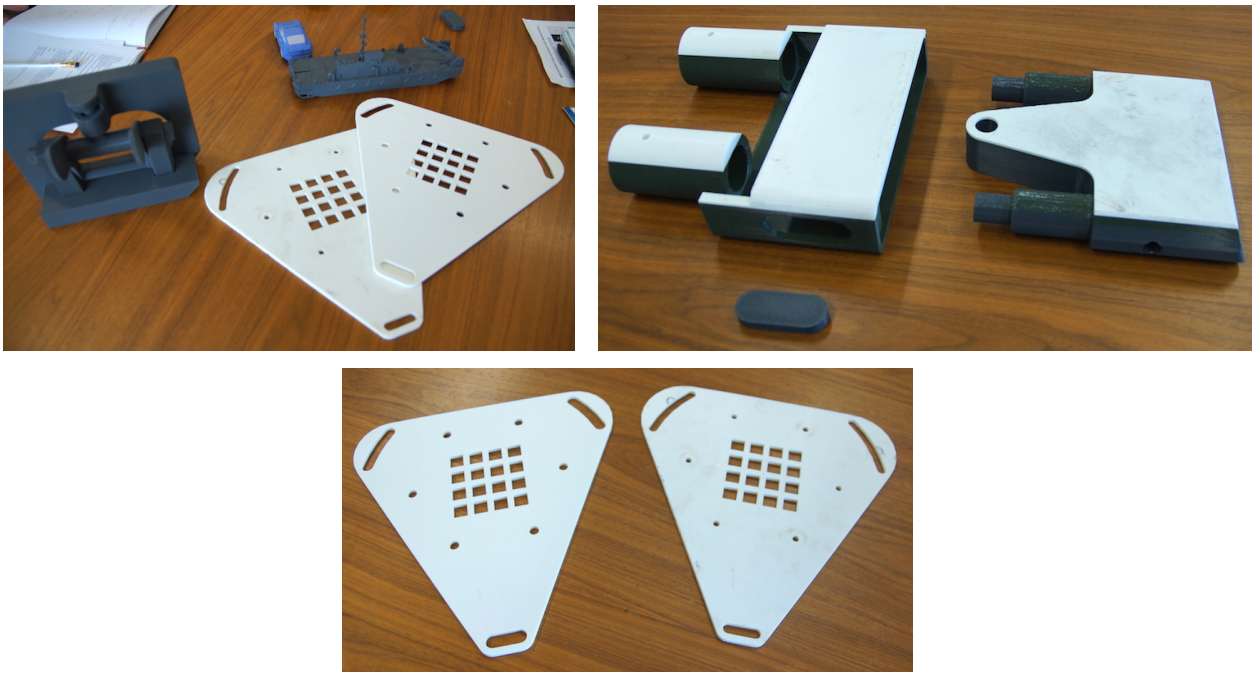

Figure 2: Parts printed by 3D printer at NAVFAC, Port Hueneme, CA

Figure 3: Windform SP additive manufacturing with composite polyamide based carbon filled material used for additive manufacturing (Maker Faire exhibit floor, 16-17 May 2015)

Figure 4: VR Hackathon, San Francisco, CA (22-24 May, 2015)